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SOME RESULTS OF BIOMEDICAL INVESTIGATIONS CONDUCTED DURING THE GEMINI AND APOLLO PROGRAMS (ALTERATIONS IN BLOOD AND SKELETAL APPARATUS, MINERAL AND ELECTROLYTE METABOLISM IN THE ASTRONAUTS)

V. I. Kopanev and Ye. M. Yuganov

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16. Abstract

It has been found that in the course of postflight examinations individual astronauts showed certain changes involving the blood (decrease in erythrocyte mass, leucocytosis and so forth), skeletal structure (decrease in bone density), mineral and electrolyte metabolism (washing out of calcium, iron, potassium and chloride).

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SOME RESULTS OF BIOMEDICAL INVESTIGATIONS CONDUCTED DURING THE GEMINI AND APOLLO PROGRAMS (ALTERATIONS IN BLOOD AND SKELETAL APPARATUS, MINERAL AND ELECTROLYTE METABOLISM IN THE ASTRONAUTS)[1]

V. I. Kopanev and Ye. M. Yuganov

Change in Blood Parameters. American scientists have placed great emphasis /852* during the postflight examinations on hematological studies, carrying out general analyses of blood for this purpose, as well as individual specialized studies. The results of an examination of the Gemini spacecraft crews have shown that following flights there was a completely regular decrease in the erythrocyte mass (by 7-20% in comparison with preflight studies) and to a much lesser degree in the blood and plasma volumes. Following the 14 day flight the last 2 parameters even increased in the astronauts (Table 1). Dietlein (1970) explains these differences by characteristics of the diet. Aboard the Gemini-7 the astronauts were allowed to eat and drink all they wanted. Evidently this had a favorable effect on the plasma volume and this parameter did not decrease. During the Apollo flights, rather contradictory data were obtained: the plasma volume increased slightly in the crew members of the Apollo-14 and 15 and decreased in the Apollo-16 astronauts by 9% on the average (Berry, 1973).

As we can see from Table 1, the flight was followed by a decrease in the survival time of the erythrocytes, they showed increased fragility, an increase in volume, a drop in total hematocrit, and there was a drop in the concentration of hemoglobin in the erythrocytes. There was a marked increase in the ratio between the erythrocytes in the blood from the spleen and liver, and reticulocytosis was not found (Deitlein, 1970). Studies of the Apollo astronauts showed approximately the same data but there were some differences (Table 2).

Leucocytosis accompanied by absolute neutrophilia and lymphopenia were found. The changes were brief. During a period of 24 hours following the flight, the number of leucocytes and the leucocyte formula returned to the

[1]Continuation. The first part can be found in the journal "Izvestiya AN SSSR, Seriya Bioloicheskaya," No. 5, 1973.
*Numbers in margin indicate pagination in the foreign text.

original level. The changes that were observed, in the opinion of Berry (1970a, b) arose as the result of an increased concentration of adrenaline and steroids in the blood as a reaction to the stressful effects of the flight. As far as the erythrocytes are concerned, differences were found in experiments aboard /853 the Apollo spacecraft: aboard the Apollo-7 and 8 the change in the erythrocyte mass was insignificant, aboard the Apollo-9 it was pronounced and aboard the Apollo-14, 15 and 16 the decrease was 16% on the average (Berry, 1973). During the flights of the Apollo-11, 12 and 13 this parameter was not investigated. Many theories have been proposed concerning the reasons for the decrease in the erythrocyte mass. At the present time, the most popular view is the one concerning the toxic effect of oxygen as a result of living in a 100% oxygen atmosphere and the inhibiting effect of nitrogen (Lomonaco, 1969; McCally, 1971 and others). The loss of erythrocyte mass was least during those flights in which a slight admixture of nitrogen (3 to 5%) was maintained in the cabin atmosphere. An atmosphere consisting of 100% oxygen was used aboard the Gemini and Apollo-9 spacecraft. In this case the crew members showed a significant /854 decrease in the erythrocyte mass. White et al., (1971) feel that this view must be subjected to further experimental verification. Other explanations have been proposed. Thus, Jensen (1970), on the basis of the studies of Hyatt (1970) feels that in a state of rest (physiological deafferentation) the organism undergoes a decrease in its ability to form erythrocytes. Lancaster (1970) agrees with this view but he denies the toxic effect of oxygen.

Following the Apollo-14 flight, several supplementary biochemical tests were performed on the plasma and erythrocytes and a brief hyperglycemia was found as a consequence of increased formation of catecholamines and steroids as a result of neuro-emotional stress, a decrease in the cholesterol level and uric acid volume in the blood serum apparently because of the ingestion of an unusual diet. No other biochemical changes were found which were indicative of a disturbance of the function of the liver or other internal organs. In one of the subsequent works by Berry (1973) it was found that the astronauts had a rather pronounced drop in the potassium content in the blood serum, no change in the sodium and chloride content, an increase in blood sugar after the flight, a drop in uric acid, and slight changes involving the cholesterol level, as well as hormonal changes (decrease in hydrocortisone, no change in the insulin content, significant increase in angiotensin, and so forth).

TABLE 1. SOME HEMATOLOGICAL PARAMETERS OF THE GEMINI ASTRONAUTS FOLLOWING LONG FLIGHTS

Parameters	Gemini-4 4 days		Gemini-5 8 days		Gemini-7 14 days	
	Commander	Pilot	Commander	Pilot	Commander	Pilot
Blood volume, %	—7	—13	—14	—13	+1	—1
Plasma volume, %	—4	—13	— 8	— 4	+15	+4
Erythrocyte mass, %	—12	—13	—20	—20	—19	—7
Total hematocrit, %	—	—	— 3	— 5	—8	—2
Erythrocyte halflife, days	—	—	— 6	— 9	—6,5	0
Fragility of erythrocytes	—	—	—	—	++	+
Average volume of elements in the blood, 3%	—	—	+ 4	+ 1	+9	+13
Average concentration of hemoglobin in the erythrocytes, %	—	—	—	—	—3	—5
Ratio of erythrocytes in the blood of the spleen and liver, %	—	—	—	—	+30	+13
Content of reticulocytes per 1000 erythrocytes, %	—	—	—1,2	—1,2	+0,05	—0,08

Commas indicate decimal points.

TABLE 2. CHANGES IN CERTAIN HEMATOLOGICAL PARAMETERS IN THE APOLLO ASTRONAUTS

Parameters	Apollo 7	Apollo 8	Apollo 9	Apollo 10	Apollo 11	General trend
Erythrocytes	0	+2	-2	+2	0	0
Hematocrit	0	+2	0	+2	0	0
Hemoglobin	0	+2	+2	0	0	-
Reticulocytes	0	0	-	0	0	-
Leucocytes	+3	+3	0	+2	+3	+3
Neutrophils	+2	+2	0	+3	+3	+2
Lymphocytes	-2	-2	0	-2	-2	-2
Monocytes	0	-2	0	0	-2	-2
Eosinophils	-	-	-	-2	-2	-1
Basophils	-	-	-	-2	-	0
Thrombocytes	0	0	0	0	0	0

Note: 0 - unchanged, numbers with symbols (+) and (-) indicate the standard deviations in arbitrary units (sigmas).

As far as the physiological mechanisms of the changes in certain other parameters are concerned (increased sedimentation rate, neutrophilic leucocytosis with lympho- and eosinopenia and so forth), which were frequently observed in the astronauts by N. M. Sisakyan (1965), Berry (1967, 1970a, b), N. S. Molchanov et al., (1970), Ye. N. Zhuravleva and B. Legon'kov (1972), they were quite complex. Some (Genin, Pestov, 1971) viewed them as a manifestation of an inflammatory reaction to venous stagnation, a deterioration of tissue metabolism, traumatic myosistis on the general biological level of the stress reaction. The state of hemodynamics under weightless conditions is also likely to predispose the individual to the development of hemophilic reactions involving the coagulation of the blood. Following the flight, some astronauts show a drop in the number of thrombocytes in the blood (Molchanov et al., 1970). This all indicates that under weightless conditions there are certain trends in the changes in one of the most important fluid media in the organism — the blood which are intensified when the astronauts are exposed to an atmosphere consisting of 100% oxygen.

Change in Skeletal Apparatus, Mineral and Electrolyte Metabolism. The decrease in mechanical forces acting upon the support-motor and bone-muscle apparatus under weightless conditions may lead to a demineralization of the bones, as well as a drop in muscular strength and tone (Stubbs, 1970 et al.). The influence of weightlessness on skeletal tissue in astronauts was studied during flights in the Gemini and Apollo programs (Mack et al., 1966; Hattner, 1968; McMillan, 1968; Chermin, 1969; Berry, 1970a, b; Grandpirre, 1971 et al.).

During the flights of the Gemini-4, 5 and 7 crews the density of the skeletal tissue was studied by means of a narrow beam of x-rays. The density of the bones in the wrist and fingers as well as the heel was measured in 6 astronauts before and after the flight for several weeks (Table 3). As we can see, the commander of the Gemini-4, after 4 days of flight, showed a decrease in the density of the heel tissue of 6.8-7.8%, and by 11.8% in the bones of the wrist. The pilot of the craft also showed a decrease in these values by 9.3-10.3 and 6.2%, respectively. The return of bone density to the original level required 10 days. During the flight of the Gemini-5, the decrease in the density of the heel bone of the commander of the craft was 10.3-15.1%, for the /855 wrist it was 10.0-23.2%, and the values for the copilot were 8.9 and 11.4-17.0%, respectively. Relatively slight changes were found in an examination of the crew members of the Gemini-7. In the case of the commander of the craft, the decrease in density of the heel bone, measured by means of densitometry, was only 2.5-2.9%, and 6.6-6.8% for the wrist; for the pilot these values were 2.5-2.8 and 3.8-7.8%, respectively. The majority of investigators explain this by pointing to the specific preventive measures that were taken: physical exercises during the flight, increased consumption of calcium in the diet (up to 921-945 mg per day) and so forth.

TABLE 3. CHANGE IN DENSITY OF BONE DURING SPACEFLIGHTS ON THE BASIS OF ROENTGENOGRAPHIC DATA (PERCENTAGE IN COMPARISON WITH PREFLIGHT STUDIES)

Anatomical location, crew, duration of flight	Commander of the craft	Pilot
Heel bone (normal plane)		
Gemini-4 (4 days)	- 7.8	-10.27
Gemini-5 (8 days)	-15.1	- 8.9
Gemini-7 (14 days)	- 2.91	- 2.84
Heel bone (other planes)		
Gemini-4 (4 days)	- 6.82	- 9.25
Gemini-5 (8 days)	-10.31	- 8.9
Gemini-7 (14 days)	- 2.46	- 2.54
Second joint of the 5th finger		
Gemini-4 (4 days)	-11.85	- 6.24
Gemini-5 (8 days)	-23.20	-16.97
Gemini-7 (14 days)	- 6.78	- 7.83
Second joint of the 4th finger		
Gemini-5 (8 days)	- 9.98	-11.37
Gemini-7 (14 days)	- 6.55	- 3.82

In subsequent reports by Soviet and American investigators, the fact of a moderate decrease in the density of the skeletal apparatus under weightless conditions was generally supported. This was observed by Mack (1969), Ye. N. Biryukov and I. G. Krasnykh (1970), and Berry (1970a, b) and others.

Thus, R. V. Mack (1969) used the roentgenographic method to examine the /856
crews of the Apollo-7 and 8. In each of the astronauts he studied 7 anatomical areas. The results are shown in Table 4.

TABLE 4. CHANGES IN THE DENSITY OF BONE TISSUE (%) OF SEVERAL AREAS OF THE SKELETON IN CREW MEMBERS OF THE APOLLO-7 AND APOLLO 8 FOLLOWING SPACEFLIGHTS

Skeletal tissue	Astronauts					
	SC*		CMP*		LMP*	
	Apollo 7	Apollo 8	Apollo 7	Apollo 8	Apollo 7	Apollo 8
Center of the heel bone	-5.32	-2.43	+0.74	-6.95	+2.26	-2.93
Various planes of the heel bone (average data)	-4.1	-7.08	+1.19	-6.04	+0.85	-6.50
Center of the talus	-3.6	-2.62	+1.75	-2.81	+2.89	-3.18
Joints of the 4th and 2nd finger	-9.3	-2.19	-2.04	-2.41	-6.50	+4.81
Capitate bone	-4.07	-9.6	+3.31	-12.11	-3.44	-6.65
Distal end of radius	-3.25	-8.76	+3.34	-11.06	-3.64	-11.39
Distal end of ulna	-3.02	-6.42	+2.12	-12.41	-3.41	-16.17

*SC, Spacecraft commander; CMP, command module pilot; LMP, lunar module pilot.

The observations revealed that during the flight the density of the bone tissue in all of these areas increased in the Apollo-7 commander by 3.02-9.3%; the command module pilot showed an increase by 0.74-3.34%, the lunar module pilot showed a slight increase in the density of the heel bone and there were decreases in other areas (by 3.41-6.5%). The changes in the Apollo-8 astronauts were all in the same direction. The bone density dropped in all of them: in the commander by 2.13-9.6%, in the command module pilot by 2.81-12.41% and in the lunar module pilot by 2.97-16.17%. In the majority of cases, more significant changes occurred in the bones of the hand than in the bones of the leg. An analysis of these data indicates (Mack, 1969) the possible reasons for the differences. Negative changes in the density of skeletal tissue in the Apollo-8 astronauts were more significant than in the Apollo-7 astronauts, since the latter performed physical exercise regularly. A favorable effect on the skeletal system under weightless conditions obviously consists in the "stretching"

of the muscles attached to the bones which in turn stimulates the circulation of the blood in them. The only difference involves the data from the examination of the Apollo-14 crew. Pre- and postflight examinations of the left heel bone and the distal part of the right radius and ulna using the method of adsorption of monoenergetic photons failed to indicate any washing out of mineral salts from the bones in the course of a 10 day flight. The reason for the divergence of these data is not clear (Berry, 1971a, b). It is possible that they have to do with the method of examination. In the opinion of Nordin (1970) the roentgenographic method of determining the density of bone tissue is subject to certain errors due to the existence of a layer of soft tissues around each bone. In addition, the structure of the bones themselves is not uniform. In the trabecular bone, for example, only 20% of the tissue actually consist of bone while the remaining 80% is made up of soft tissue which cannot /857
help but affect the results of densitometry. Although such views have a certain degree of validity, it seems to us that there is no basis for objecting to the effectiveness of the roentgenographic studies. A confirmation of this view is the success achieved in using this method both in the USA and in the USSR as well as the results of a study of mineral metabolism, especially calcium metabolism, which indicates a definite change in the organism. Wheydon, Lutwak (1969) and others performed a careful study of the metabolic processes in the crew members of the Gemini-7 during their 14 day orbital flight. Analyses of the fecal masses, sweat and urine were performed in the course of 10 days prior to the launch, during the flight and afterward for 4 days in the recovery period. A strictly governed food ration for the astronauts, the excretion of calcium, magnesium, phosphorus, nitrogen, sodium, potassium and also 17-oxycorticosteroids (17-ox), aldosterone and catecholamines were determined. The authors point out however that the method of collecting the material was not completely effective (especially in the case of urine) during orbital flight in all cases. Due to the unusual nature of the situation, it was lost or there were errors in adding the preservatives. This was taken into account by the investigators in evaluating all of the parameters. It was found that the excretion of calcium with the urine in all of the astronauts during the first 7 days did not change significantly but in the case of F. Borman, beginning

on the 8th day, there was a definite increase in its content in the urine and this picture was retained afterward (Table 5, Figure 1).

TABLE 5. METABOLIC BALANCE IN ASTRONAUTS F. BORMAN (SC) AND J. LOVELL (P) DURING THE FLIGHT OF THE GEMINI-7

FOLDOUT FRAME

Period of the experiment	Duration of examination, days	Material	Potassium, g		Magnesium, g		Sodium, meq		Potassium, meq		Phosphates, g		Sulphates, g		Nitrogen, g		Chlorides, meq	
			SC	P	SC	P	SC	P	SC	P	SC	P	SC	P	SC	P	SC	P
Preflight	10	Food	1,103 ±0,044	1,108 ±0,48	0,338 ±0,011	0,366 ±0,018	151,7 ±15,7	123,6 ±9,6	128,9 ±22,9	116,0 ±15,5	2,548 ±0,239	2,373 ±0,15	2,737 ±0,338	2,562 0,304	24,78 ±2,36	22,32 ±1,44	—	—
		Urine	0,215 ±0,024	0,159 ±0,017	0,117 ±0,014	0,101 ±0,15	172,4 ±16,8	143,7 ±28,3	98,9 ±17,0	74,6 ±7,6	1,323 ±0,091	1,259 ±1,133	1,344 ±0,292	1,077 ±0,433	22,83 ±2,65	20,36 ±2,2	145,3 ±10,9	129,3 ±23,0
		Feces	0,765	0,431	0,221	0,173	3,0	4,9	7,9	6,9	0,557	0,407	0,182	0,09	1,78	1,22	18,4	16,1
		Sweat	0,026	0,023	0,007	0,006	24,7	25,2	10,4	14,4	0,00	0,00	0,004	0,05	0,19	0,36	0,1	0,5
		Balance	+0,097	+0,495	+0,043	+0,086	−48,4	−50,2	+11,7	+20,1	+0,668	+0,707	+1,207	+1,39	−0,02	+0,38	—	—
Flight	14	Food	1,042 ±0,251	1,042 ±0,251	0,198 ±0.04	0,198 ±0,04	145,1 ±28,4	145,1 ±28,4	36,8 ±8.9	36,8 +8,9	1,362 +0,161	1,362 ±0,161	0,874 ±0,163	0,874 +0,163	15,81 ±2,85	15,81 ±2,85	—	—
		Urine	0,238 ±0,032	0,162 ±0,019	0,129 ±0,033	0,097 ±0,016	198,3 ±41,1	181,8 ±22,6	93,4 ±41,6	50,9 ±6,3	1,741 ±0,442	1,577 ±155	1,254 ±0,21	1,019 +0,102	17,8 ±2,27	16,24 ±1,86	65,7 ±42,5	146,4 ±22,1
		Feces	0,796	0,766	0,115	0,109	2,3	10,3	1,1	7,2	0,311	0,288	0,127	0,096	1,31	0,87	1,4	0,2
		Sweat	0,014	0,016	0,006	0,007	18,6	2,9	6,9	1,6	0,00	0,00	0,003	0,002	0,003	0,04	0,2	2,2
		Balance	−0,06	+0,098	−0,052	−0,015	−72,1	−49,9	−64,6	−22,9	−0,690	−0,504	−0,51	−0,243	−3,34	−1,34	—	—
Postflight	4	Food	1,102 ±0,111	1,090 ±0,119	0,371 ±0,052	0,359 ±0,035	167,2 ±29,3	125,3 ±30,4	122,9 ±20,9	177,4 ±12,5	2,424 ±0,292	2,376 ±0,168	2,655 ±0,276	2,588 ±0,191	22,82 ±3,36	22,02 ±2,48	—	—
		Urine	0,286 ±0,002	0,172 ±0,014	0,093 ±0,011	0,093 ±0,006	140,1 ±33,8	74,5 +21,8	90,3 ±3,9	63,4 ±14,1	1,563 ±0,286	1,296 ±0,542	1,689 ±0,453	1,529 ±0,104	25,34 ±3,97	19,92 ±2,91	126,7 ±48,6	65,5 ±26,8
		Feces	0,769	0,766	0,148	0,109	6,5	10,3	9,6	7,2	0,503	0,289	0,104	0,096	1,21	0,97	0,3	0,2
		Sweat	0,043	0,045	0,014	0,017	12,0	9,8	11,0	11,4	0,00	0,00	0,004	0,010	0,26	0,29	15,1	15,3
		Balance	+0,004	+0,107	+0,115	+0,140	+8,6	+30,7	+12,0	+35,6	+0,358	+0,791	+0,883	+0,953	−3,99	+0,84	—	—

Commas indicate decimal points.

The content of phosphates in the urine rose during the first 9 days and then dropped almost to control levels (Table 5, Figure 1). The final calcium balance was negative in both astronauts, which has to do with the increased excretions of this substance with the feces in the pilot while there was an increase in its excretion with the urine in the commander. In both these astronauts, the nitrogen content in the urine during the flight decreased but returned to preflight values after the flight. However the consumption of nitrogen with food was sharply decreased and this was the reason for the negative nitrogen balance (Table 5). The excretion of magnesium and sulphates showed a similar pattern to that of nitrogen. The nature of potassium metabolism in the astronauts varied (Table 5). At the beginning of the flight, the potassium excretion with the urine in the case of the commander decreased against a background of a noticeable decrease in its intake with the diet. In the second half of /858 the flight the excretion of potassium with the urine rose. After the flight, potassium excretion dropped but its intake with the diet rose. In the case of the pilot, however, there was only a slight drop in potassium excretion with the urine during the entire flight and the return to normal after its completion. Data on sodium and chloride excretion in the urine in the case of astronauts are presented in Figure 2.

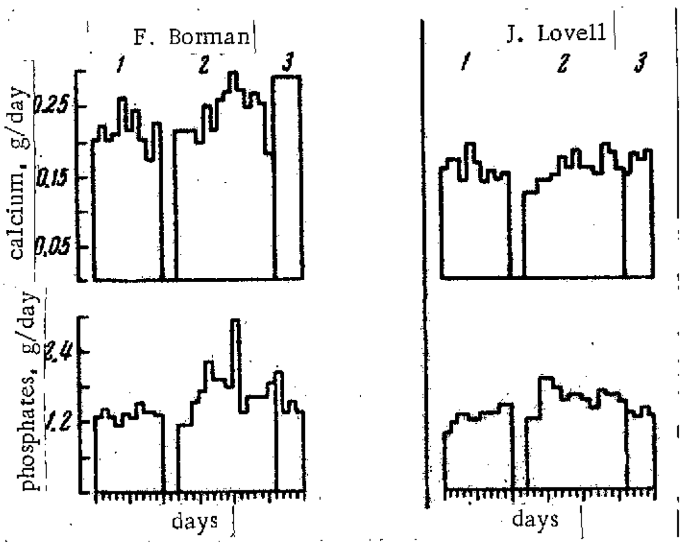

Figure 1. Excretion of Calcium and Phosphates in the Crew Members of Gemini-7: 1, Before the Flight; 2, During the Flight; 3, After the Flight.

As we can see, during the flight the excretion of sodium in the case of F. Borman was significant during the first hald and in the case of J. Lovell during the second. During the postflight period, however, both astronauts showed a retention of sodium in the organism. At the same time there was a shift in the chloride level. Borman showed a decline during the first 10 days of the flight while Lovell showed this during the postflight period.

Considerable interest attaches to the data on the excretion of hormones (Figure 3 and 4).

In the case of Lovell a maximum level of adrenaline and noradrenaline was observed on the day of the launch and on the day of splashdown, in other words at the most "stressful" periods. Excretion of catecholamines in S. Borman was about the same. The level of excretion of 17-ox during the entire orbital flight was comparatively low. In both astronauts it rose on the day of splashdown (Figure 3). The aldosterone level in the urine rose during the flight and immediately after splashdown (Figure 4). Papers by Whedon and Lutwak (1969) were essentially the first extensive studies of this problem. Subsequently the data they obtained were confirmed and reinforced. Thus, in a paper by Brodzinski et al. (1971) data were presented on mineral metabolism in the crew members of the Apollo-7, 8, 9 and 11. Using the method of neutron activation to analyze the feces collected during the flight aboard the spacecraft as well as urine, samples of which were collected prior to the flight and afterward, and by comparing them with the data on the consumption of the elements (according to NASA data), the office examined the degree of divergence and possible consequences of disruption of mineral balance (Table 6).

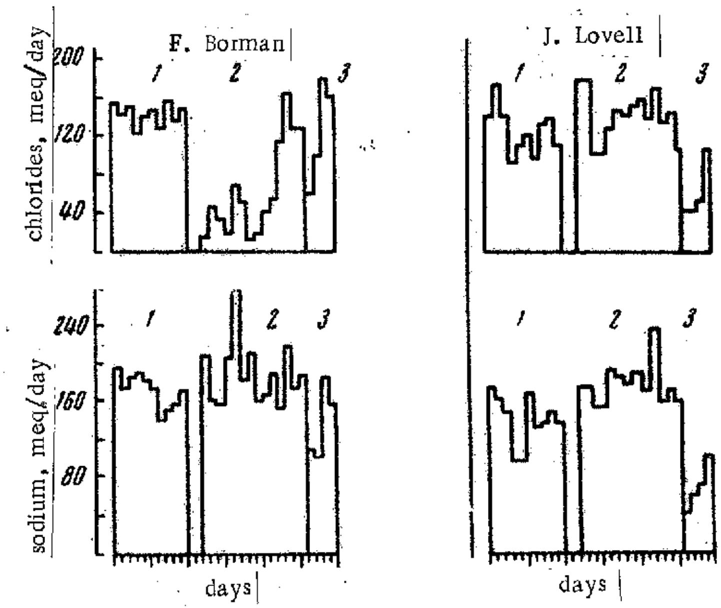

Figure 2. Excretion of Sodium and Chlorides with the Urine in the Crew Members of the Gemini-7: 1, Before the Flight; 2, During the Flight; 3, After the Flight.

As we can see the potassium losses for 24 hours were 634 mg which amounts to 0.0605% of the total calcium content in the organism for a 70 kg man. It was interesting to note that during the first 3 flights the rate of excretion was higher (990 mg) than on the last 2 (220 mg). The excretion of potassium from the organism also followed roughly the same pattern. For all flights, on the average, the rate of potassium loss was 296 mg (0.16% of the total K content in the organism). On the first 3 flights it was higher (668 mg) and on the last 2 lower (48 mg). As far as iron is concerned, it was excreted in all flights at approximately the same rate (about 6.4 mg per day). Similar changes in the mineral metabolism under weightless conditions (excretion of potassium, sodium, calcium, iron and other elements) are compensated by the organism during the postflight period. A study of the electrolytes in the urine and blood plasma following the flights showed a tendency toward retention in the organism. Figure 5 shows the results of studies of the potassium content in the urine for the Gemini-7 pilot. It is clear that during the flight there was already a drop in the potassium excretion which persisted for 24 hours following the flight. The assumption regarding the reduction of the total potassium content in the organism found a direct confirmation in the studies with K^{42} aboard the Apollo-13 and 14. Gamma spectrometry showed a significant drop in the total potassium content in the organism, while in the case of the Apollo-14 crew it persisted for 17 days after the flight (Berry, 1971a, b). This was also found in the study of the Apollo-15 crew. Obviously sodium retention reflects a tendency toward normalization of water-salt equilibrium and potassium retention is explained by processes involving the reduction of muscle proteins. /860

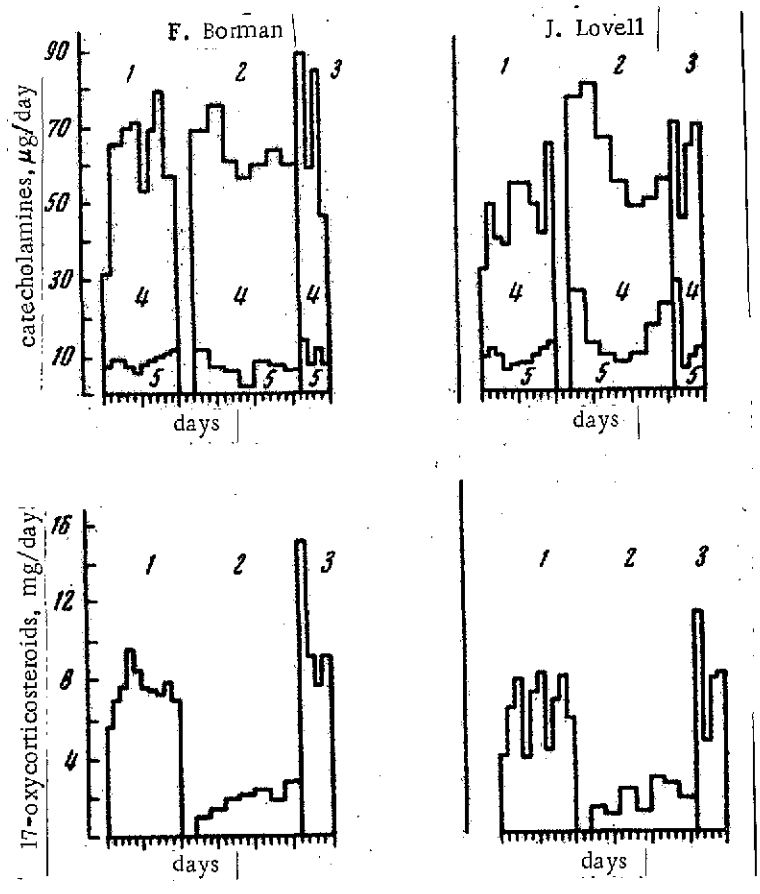

Figure 3. Excretion of Hormones in the Crew Members of the Gemini-7: 1, Before the Flight; 2, During the Flight; 3, After the Flight.

Figure 6 shows the data on the content of electrolytes in the urine of the command module pilot of Apollo-14.

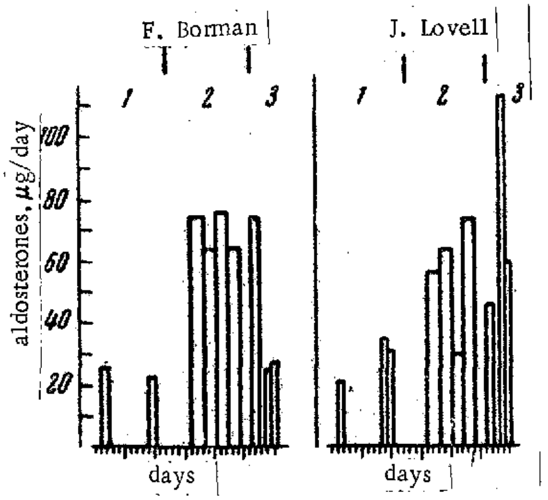

Figure 4. Excretion of Aldosterone in the Crew Members of the Gemini-7: 1, Before the Flight; 2, During the Flight; 3, After the Flight.

Finding electrolytes in the urine is a typical consequence of the effects of spaceflight on the human organism. This was confirmed by an analysis of the chemical composition of urine for other crew members of the Apollo spacecraft (Table 7).

Berry (1973) presented several summaries of the biochemical changes which have been observed in the astronauts' urine during spaceflights. In particular, the excretion of sodium and chlorides with the urine decreased slightly during the flight and was markedly inhibited after the flight. As far as potassium is concerned, the data were indeterminate. The content of steroids (aldosterone, hydrocortisone) and catecholamines in the urine increased. The crew members of the Gemini spacecraft showed increased excretion of calcium with the urine during the last phase of the flight, while the Apollo astronauts did not. /862

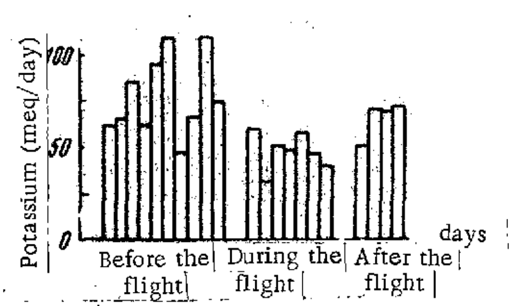

Figure 5. Potassium Content in the Urine of the Pilot of the Gemini-7.

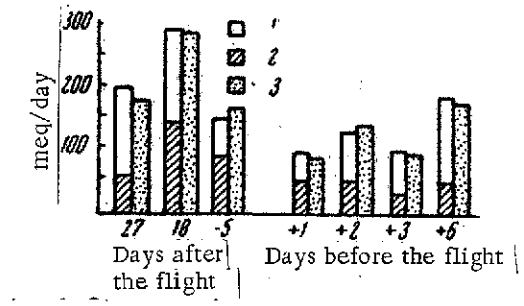

Figure 6. Content of Electrolytes in the Urine of the Command Module Pilot of the Apollo 14 Before and After the Flight: 1, Sodium; 2, Potassium; 3, Chlorides.

The researchers devote particular attention to an analysis of the consequences which may follow for the organism in the event of extreme excretion of certain substances. Thus, in the opinion of Dick (1966) and Vrodzinski et al. (1971), loss of calcium in amounts recorded during the flight of the Apollo-10 and 11 as well as the experiments involving simulation of weightlessness may be permissible for several years. Another viewpoint is held by L. I. Kakurin and Ye. N. Biryukov (1966). They suggest that the losses of calcium, which possesses a high degree of physiological activity, may cause a number of functional disturbances involving the cardiovascular system, the function of the coagulation of the blood and so forth. Excretion of calcium from the organism under weightless conditions, according to general opinion, is explained by the insufficient stress imposed upon the skeletal musculature and the elimination of weight stress stress. Ye. N. Biryukov and I. G. Krasnykh (1970), in addition to these factors, also cite several other mechanisms of regulation of calcium metabolism, particularly hormonal ones. It is possible that the calcium ions are mobilized from the skeletal deposits of cations to eliminate the electrolyte imbalance which arises under weightless conditions. Berry (1971), supporting Biryukov and Krasnykh, mentions the necessity for studying the content of parathyroid hormones and calciotinin for the purpose of learning about the mechanisms by which mineral salts are washed out of the bones.

There is still a great deal which is not clear concerning the excretion of electrolytes of sodium and potassium. On the basis of data which are far from complete (Whedon, Lutwak, 1970; Brodzinski et al., 1971) it has been established that the losses of these elements are insignificant. However, in this case it is clear that there is no basis for indifference, keeping in mind the role of these substances in the normal functioning of the central nervous system (CNS) in the regulation of osmotic pressure and the transport of a number of very important substances across the cell membrane. The iron balance /863 plays an important role in the retention of the vital activity of the organism. As we can see from the above, the rate of excretion of this substance is independent of the duration of the flight and is quite significant in magnitude. In the opinion of Brodzinski et al. (1971), it may be possible for astronauts to develop and anemic condition on long flights. The reasons for the intensive excretion of iron are by no means clear. One possible reason is the oxygen--rich atmosphere of the spacecraft cabin. This means that iron is excreted from the organism which comes from the mature and decomposed erythrocytes. In addition, we cannot exclude the possibility that such a great loss is due to hemorrhaging, which might possibly be caused by giving the astronauts radioactive chromium during the preflight period (Brodzinski et al., 1971).

TABLE 6. AVERAGE DAILY BALANCE OF CALCIUM, POTASSIUM AND IRON IN THE ORGANISM OF THE APOLLO ASTRONAUTS

FOLDOUT FRAME

Spacecraft	Astronauts	Calcium, mg: Intake with the diet	Calcium, mg: Excreted with the feces	Calcium, mg: Total excreted*	Calcium, mg: Ratio between amount excreted and amount taken in	Calcium, mg: Mass-balance (mg/day)	Potassium, mg: Intake with the diet	Potassium, mg: Excreted with the feces	Potassium, mg: Total excretion**	Potassium, mg: Ratio between amount excreted and amount taken in	Potassium, mg: Mass-balance (mg/day)	Iron, mg: Intake with the diet	Iron, mg: Excreted with the feces	Iron, mg: Total excretion***	Iron, mg: Ratio between amount excreted and amount taken in
Apollo-7	Average for the crew	836	1140	1430	1,7	—590	—	—	—	—	—	8,1	15,7	15,7	1,9
Apollo-8	SC****	427,2	1150	1440	3,36	—1010	1229	499	3020	2,46	—1795	5,0	13,3	13,3	2,7
Apollo-9	SC	562,5	1119	1490	2,64	—930	1677	253	1540	0,916	+141	7,1	11,6	11,6	1,6
Apollo-9	CMP****	494,3	1100	1380	2,78	—880	1386	2,76	1670	1,21	—236	5,9	13,2	13,2	2,2
Apollo-9	LMP	489,0	2260	2330	5,78	—2340	1708	403	2440	1,43	—732	6,5	17,2	17,2	2,6
Apollo-10	Average for the crew	832,9	730	910	1,1	—80	1340	176	1070	0,737	+273	5,1	6,7	6,7	1,3
Apollo-11	Ditto	1000,3	1090	1360	1,36	—360	1751	350	2120	1,21	—3,67	8,0	16,4	16,4	2,1
Average		767,7	1120	1400	1,83	—635	1527	300	1820	1,19	—296	6,8	13,2	13,2	1,9

*Assuming that the feces contain 80% of the total calcium excreted from the organism.

**Assuming that the feces contain 16.5% of the potassium excreted from the organism.

***Assuming that the feces contain 100% of the iron excreted from the organism.

****SC, spacecraft commander; CMP, command module pilot; LMP, lunar module pilot.

TABLE 7. CHEMICAL COMPOSITION OF THE URINE OF THE CREW MEMBERS OF THE APOLLO SPACECRAFT

Parameter	Apollo 8	Apollo 9	Apollo 10	Apollo 11	Total
Urine volume	—	—	—	—2	—
Specific gravity	+2	—	—	—	—
Oxyproline	+3	—	—	—	+3
Uric acid	+3	—	—	—2	—
Creatinine	+3	—	—2	—	—
Inorganic phosphorus	+3	—	—	—2	—
	—	—1	—2	—2	—1
	—2	+2	—2	—2	—
	—	—1	—2	—1	—1
	—2	—	—	—2	—
	—1	—2	—2	—2	—2

Note: The numbers with the "+" sign and "-" sign designate the standard deviations (positive or negative) in arbitrary units.

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